

Final Report

Supplement to Remote Sensing and Modeling of Coherent Structures in River and Estuarine Flows

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This grant provided follow-on support for the FY05 MURI designated COHSTREX (award number N00014-05-1-0485). As such, this final report is similar to the COHSTREX final report.

LONG-TERM GOALS

The long-term goals of this research were to combine state-of-the-art remote sensing and *in situ* measurements with advanced numerical modeling (a) to characterize coherent structures in river and estuarine flows and (b) to determine the extent to which their remotely sensed signatures can be used to initialize and guide predictive models.

OBJECTIVES

Coherent structures are generated by the interaction of the flow with bathymetric and coastline features. These coherent structures produce surface signatures that can be detected and quantified using remote sensing techniques. Furthermore, a number of relationships between coherent structures and flow characteristics have been suggested that have the potential to allow flow parameters (e.g. mean velocity, bottom roughness, shear, and turbidity) to be inferred from remote measurements. The objectives were to test the following four hypotheses:

1. Flow parameters can be inferred from remotely sensed signatures of coherent structures.
2. Numerical models can be constrained with these inferred parameters.
3. The effect of stratification on the strength of coherent structures can be used to detect the presence or absence of stratification and the location of the fresh/salt water interface.
4. Numerical and field experiments can be used together to predict, interpret, characterize, and understand coherent structures.

APPROACH

The key to this project was an interactive process that blended sophisticated remote sensing, *in situ* measurements, and numerical simulation. Our approach was to conduct closely coupled field and numerical model experiments to test the hypotheses listed above. We conducted two major

field experiments with both *in situ* and remote sensing measurements – the first was in Year 2 and the second in Year 4. Preliminary experiments were conducted in Years 1 and 3 to aid in the design of the major field efforts. The research involved four main areas - (1) *in situ* measurements, (2) remote sensing, (3) modeling, and (4) physics and classification of coherent structures. The *in situ* field measurements were used to characterize the overall flow field to investigate the generation of coherent structures at specific sites, and initially, to provide boundary inputs for the numerical models. The surface signatures of coherent structures in the same region were detected using remote sensing techniques and compared with the *in situ* and model results. The numerical models served three roles, viz., (1) precursor simulations in which existing bathymetry and assumed regional forcing will allow us to guide the measurement plans, (2) detailed simulations of both the region and specific local areas for comparison to field-determined coherent structures, and (3) simulations to aid in characterizing the mechanisms by which observed coherent structures are formed, to evaluate the sensitivity of these generation mechanisms to variations in forcing, and to predict the surface signature that such structures generate. Results from the *in situ* field observations, remote sensing, and numerical model runs were synthesized into a classification scheme that included all observed coherent structures. Predictive scaling relationships were developed in order to generalize the results from this study to other systems. The result of this integrated approach were a thorough investigation of the mechanisms and evolution of coherent structures in rivers and estuaries in order to link their surface expressions to subsurface flow features.

The project participants were organized into teams identified by the main areas of interest listed above: Remote Sensing: A. Jessup, W. Plant (APL-UW),; Modeling: R. Street and O. Fringer (Stanford); In situ Measurements: S. Monismith and D. Fong (Stanford); Physics and Classification: A. Horner-Devine.

The project supported one MS student (Brownyn Hayward, UW-CEE), two PhD students (Sarah Giddings and Bing Wang, Stanford-CEE), and two postdoctoral fellows (Chris Chickadel, APL-UW, and Mike Barad, Stanford-CEE).

To date, the project has produced 7 published and 2 submitted peer-reviewed journal articles, 1 MS thesis, and 2 PhD theses. We anticipate that at least 3 additional manuscripts will be submitted to peer-reviewed publications within the next year.

The results of the project to date are summarized in the following publications:

Articles in Peer-Reviewed Journals: Published

1. Chickadel, C., S. Talke, A. Horner-Devine, and A. Jessup (2011), Infrared based measurements of velocity, turbulent kinetic energy, and dissipation at the water surface in a tidal river, *Geosci. Rem. Sen. Let.*, *in press*.
2. Chickadel, C. C., A. R. Horner-Devine, S. A. Talke, and A. T. Jessup (2009), Vertical boil propagation from a submerged estuarine sill, *Geophysical Research Letters*, 36.

3. Giddings, S. N., D. A. Fong, and S. G. Monismith (2011b), Role of straining and advection in the intratidal evolution of stratification, vertical mixing, and longitudinal dispersion of a shallow, macrotidal, salt wedge estuary, *J. Geophys. Res.-Oceans*, 116.
4. Plant, W. J., et al. (2009), Remotely sensed river surface features compared with modeling and in situ measurements, *J. Geophys. Res.-Oceans*, 114.
5. Talke, S. A., A. R. Horner-Devine, and C. C. Chickadel (2010), Mixing layer dynamics in separated flow over an estuarine sill with variable stratification, *J. Geophys. Res.-Oceans*, 115.
6. Wang, B., O. B. Fringer, S. N. Giddings, and D. A. Fong (2009), High-resolution simulations of a macrotidal estuary using SUNTANS, *Ocean Modelling*, 28(1-3), 167-192.
7. Wang, B., et al. (2010), Modeling and understanding turbulent mixing in a macrotidal salt wedge estuary, *J. Geophys. Res.-Oceans*, 116.

Articles in Peer-Reviewed Journals: In Review

1. Giddings, S. N., et al. (2011a), Frontogenesis and frontal progression of a trapping-generated estuarine convergence front and its influence on mixing and stratification, *Estuaries and Coast*, in review.
2. Wang, B., G. Zhao, and O. Fringer (2011), Reconstruction of vector fields for semi-Lagrangian advection on unstructured, staggered grids, *Ocean Modelling*, in review.

Dissertations

1. Giddings, S. (2010), Dynamics of a shallow, macrotidal, strongly stratified estuary, PhD Dissertation, Stanford University.
2. Hayworth, B. (2007), Observations of Tidally Generated Coherent Structures in the Snohomish River Estuary, MS Dissertation, University of Washington.
3. Wang, B. (2011), Multiscale numerical simulation of a complex macrotidal tidal-river estuary, PhD Dissertation, Stanford University.

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